EVALUATION of a 7 kV 80 kA SGTO MODULE[*]

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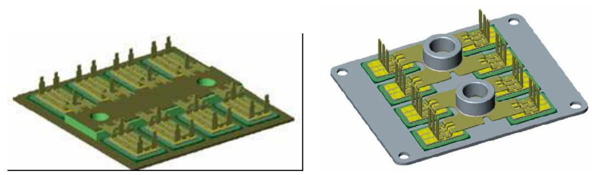
Abstract

This work was undertaken to investigate the switching performance of Super GTO's (SGTO) under conditions of fast rise times up to 25 kA/us, high peak current up to 80 kA, blocking voltage of 7 kV and pulse width of 100 us. The device under test is a switch that is made of two 3.5 kV modules placed in series; each containing eight SGTO die in parallel. The SGTO die developed by Silicon Power Corporation (SPCO) have a very small gate structure of approximately 10 µm. The benefit of this small gate structure is that it allows the device to reach full conduction faster than a conventional thyristor and is therefore optimized for fast turn-on (high di/dt). The SGTO die is a very efficient device having a current density of 29.7 A/mm^2 at 10 kA. Each SGTO die can hold of 3.5 kV and can conduct 10 kA. The efficiency of the SGTO die warrants evaluation of this dual module SGTO switch that is rated at 7 kV and 80 kA. The evaluation of the dual module will also determine its overall ability to be used in other voltage and current configurations for various applications by determining its safe operating area (SOA). We have evaluated the switch at 6 kV at a maximum current of 86 kA over a 120 µs pulse width and with a di/dt of 25 kA/µs.

I. INTRODUCTION

A single 3.5 kV 80 kA prototype module, shown in figure 1a, yielded promising results for pulse power applications producing a pulse width of 150 us at 48 kA. However, the design did not allow for balanced current sharing among the eight die due to the common cathode connection as seen in figure 1a. This was solved by dividing the modules' current path in two, thus having only four die connected together as shown in figure 1b. By creating two identically inductive paths, current distribution will be more efficient. The 7 kV, 80 kA module was evaluated to determine how well two modules perform while being connected in series. The performance of this module will determine the feasibility of a 10 kV, 400 kA switch that will contain eighteen modules, six parallel stacks of three modules in series



1a. **1b.**

Figure 1a. Prototype SGTO module layout.
1b. Redesigned SGTO module layout.

II. TESTING

The 7 kV, 80 kA module is first hi-potted with the gate connected to the cathode to ensure that the modules can indeed hold off 3.5 kV each. To evenly divide the voltage across the two 3.5kV modules that are in series a resistor network having a 1MegΩ resistance is placed in parallel with each module to divide the voltage as shown in figure 2.

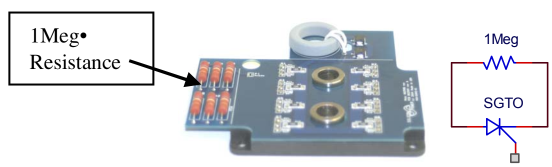


Figure 2. 3.5kV 80kA module with schematic showing 1MegΩ resistor network.

These balancing resistors must be in tact to ensure that each module is subjected to half of the applied voltage. After hi-potting, the module was placed into a RLC ring-down circuit to verify its voltage and current ratings. The 7 kV module was then connected to a dual 5-stage, type-D, pulse forming network (PFN) shown in figure 3. The PFN has a total line inductance of 860 nH and a total capacitance of 1750 uF. The module was switched at incremental voltages until the maximum current is reached. After the maximum current is reached, the module was then switched at its maximum current for 1,000 shots at a rate of one shot

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14. ABSTRACT
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per minute. The switch and the load were forced –air cooled during testing.

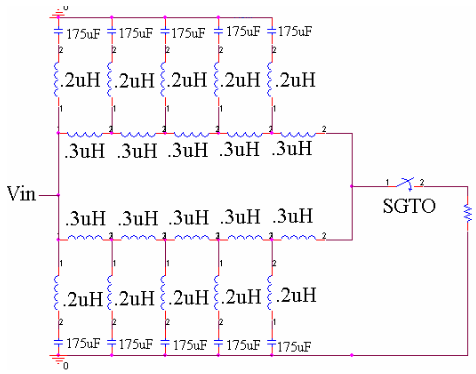

Figure 3. Pspice schematic of PFN used to test 7kV 80kA module.

III. RESULTS

The 7 kV, 80 kA module performed well in the preliminary tests using the ring-down circuit. The 7kV module was taken up to 6.5kV with a maximum current of 69kA a di/dt of 25 kA/µs and a pulse width of 60us at 50% of peak current as shown in figure 4.

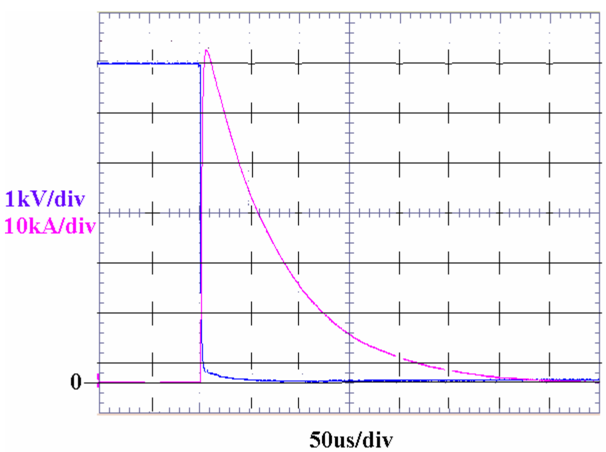

Figure 4. Voltage and current switching waveforms from the ring-down circuit at 6.5kV.

After this test the 7kV module was placed in the PFN circuit described in figure 3 were it was switch at 500v increments to ensure that the PFN and the module was working properly until 7 kV was reached were the peak current was 95 kA with a pulse width of 121 µs at 50% of peak. Even though the maximum current was exceeded, the switch showed no sign of damage and continued to work properly at 6 kV were the peak current was 80 kA. Therefore the one shot per minute test was conducted at 6 kV with a peak current of 80 kA, a di/dt of 15 kA/µs and a pulse width of 121 µs at 50% of peak current; so the 7 kV module would not be overstressed due to excess current and fail before verifying if could handle its rated current for 1,000 switches. After shot 641 the 7 kV module was performing well with no signs of degradation. At that point we paused testing to tighten the load and various connections, unfortunately the load was accidentally shorted causing more than 300 kA to flow through the switch at shot 642 as shown in figure 5. This caused the 7 kV module to fail violently in so much that the two 3.5 kV were welded together and the 1/8" bus bar was distorted as shown in figure 6. After this failure the 7 kV module would not block any voltage.

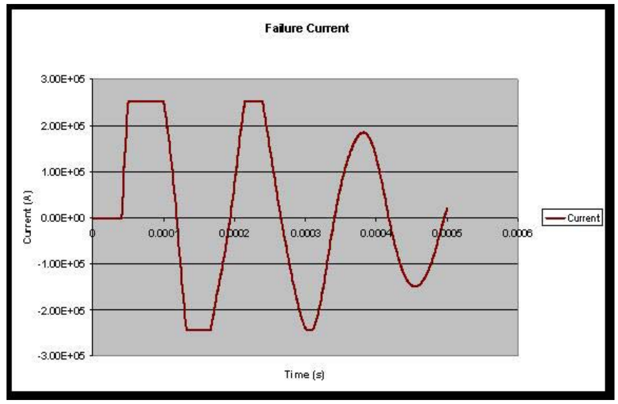

Figure 5. Current with load shorted.

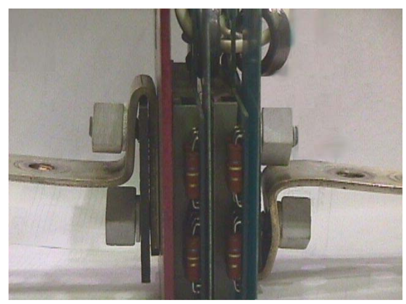

Figure 6. Failed 7kV module with bus bar attached.

After correcting the problem another 7 kV module was placed in the ring-down circuit and then the PFN and subjected to the exact same test as its predecessor. The voltage and current waveforms from shot 1000 of the one shot per minute test is shown in figure 7. The variation between the waveforms of shot 1 and 1000 had about a 1% difference as shown in figure 8.

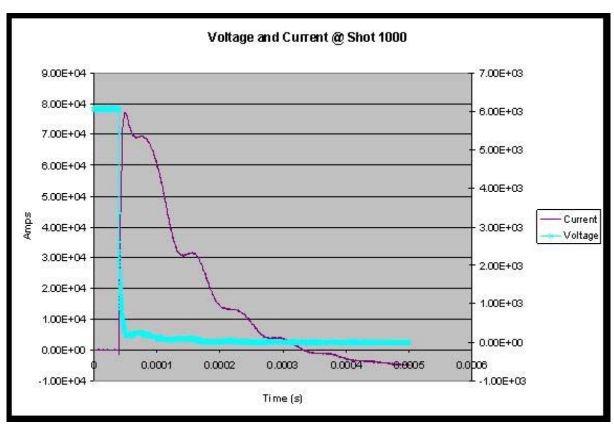

Figure 7. One thousandth shot of testing.

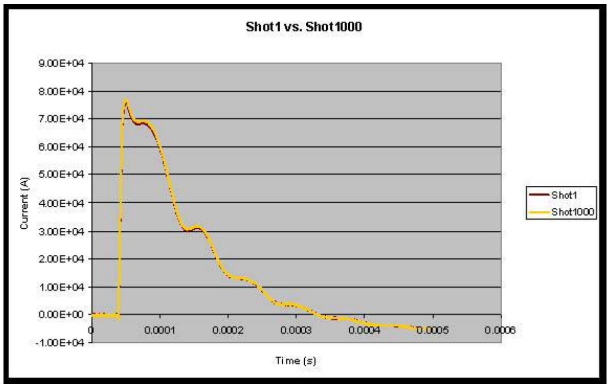

Figure 8. Shot 1 and Shot 1000 overlay.

IV. CONCLUSION

With one 7 kV, 80 kA module successfully completing 641 and the other one completing 1,000 shots at a rate of once per minute, it is clear that the 3.5 kV module will perform well if it is used in a 10 kV, 400 kA configuration where it will only need to conduct 66 kA and hold off 3.3 kV. The di/dt minimum requirement for the 10 kV 400 kA module is only 50 kA/μs which would require each 3.5 kV module to handle a di/dt of only 8.3 kA/μs. This implies that a 10 kV 400 kA module could successfully handle a di/dt of at least 144kA/μs once and 90 kA/μs for 1,000 switches. The next test for the 7 kV module is to complete 1,000 shots at a 1 Hz rate in 3 shot burst with a one minute interval. The performance of the 7 kV, 80 kA module has let to the manufacture of a 10 kV, 400 kA module which consist of 18 3.5 kV modules six in parallel stacked in series with three as shown in figure 9. This 10 kV, 400 kA module has a volume of .18 ft^3(.057 m^3) making it much smaller than conventional vacuum tube switches that have the same type of voltage and current rating.

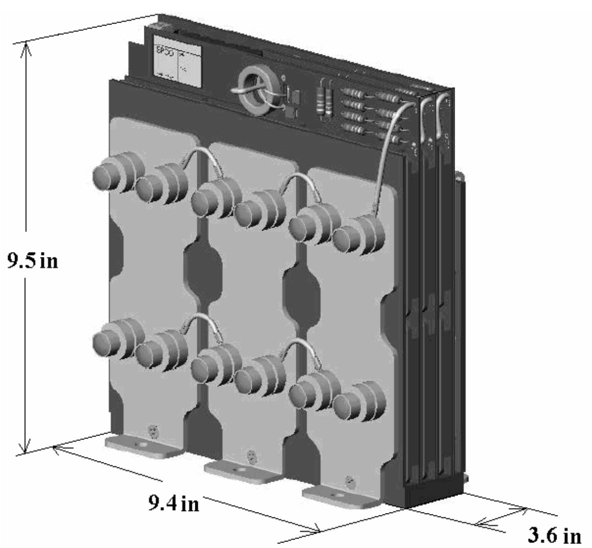

Figure 9. 10 kV, 400 kA module with bus bars.

REFERENCES

[1] T. F. Podlesak, R. L. Thomas, F. Simon, "Preliminary evaluation of super gtos in pulse application," IEEE Trans. Plasma Sci., Aug. 2005 Special Issue, Available: www.ieeetps.org.

[2] T.F. Podlesak, F.M. Simon, S. Schneider, "Single Shot and Burst Repetitive Operation of Involute Gate 125mm Symmetric Thyristors up to 221 kA with a di/dt of 2.0 kA/μs," *IEEE Transactions on Plasma Science, 28,* October 2000, pp. 1528-1532.

[3] Vic Temple, "ThinPak Technology Shrinks Power Modules, Power Hybrids and Ultra-High Speed Switching Devices," *PCIM*, *26*, May 2000, pp. 32-38

[4] R. J. Adler, "Pulse power formulary," North Star Research Corp., Mar. 2001

[5] I. Grekov, "Mega and gigawatts-ranges, repetitive mode semiconductor closing and opening switches," *Digest of Technical Papers, 11th IEEE International Pulsed Power Conference*, Baltimore, MD, July 1997, pp. 425-429